Dynamics of Boundary Currents and Marginal Seas

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LONG TERM GOALS

The long-term goals of this research are to understand the dynamics of ocean circulation near continental margins, with emphasis on western boundary current systems and circulation and exchange processes in marginal seas.

OBJECTIVES

Research during the past year has been focused on studies of the marginal seas of the northwestern Indian Ocean: the Red Sea and the Arabian Gulf. Our objective has been to use recent field measurements in the Bab el Mandeb and Straits of Hormuz, respectively, to study the exchange dynamics in these straits and to use these results along with model simulations to constrain the general circulation and air-sea exchange budgets of the marginal seas.

APPROACH

Measurements collected in these programs have consisted of moored time series observations of currents using profiling (ADCP) and conventional current meters, and water properties using temperature/salinity chain arrays, along with seasonal hydrographic surveys and local meteorological and tide gauge measurements. Modeling efforts include the application of analytical models for study of atmospherically forced fluctuations in the straits and regional numerical simulations with the Miami Isopycnal Coordinate Model (MICOM) to study the combined buoyancy and wind forced circulations and exchanges in the marginal seas.

WORK COMPLETED

1. A new survey was conducted of the Red Sea aboard the R/V Maurice Ewing in August 2001. The cruise was successful and it provided an excellent data set documenting the summer conditions in the Red Sea, including a shipboard ADCP survey, hydrographic/lowered-ADCP station data, and marine meteorological data and surface fluxes.

2. Final estimates of the surface heat and freshwater fluxes over the Red Sea and Arabian Gulf basins were produced from *in-situ* data in the respective straits, allowing a critical evaluation of available surface flux products for these regions. The flux constraints provided by the *in-situ* data revealed important biases in several of the surface flux terms and is leading to improved parameterizations and treatments of these fluxes for the regional atmospheric conditions.

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14. ABSTRACT

The long-term goals of this research are to understand the dynamics of ocean circulation near continental margins, with emphasis on western boundary current systems and circulation and exchange processes in marginal seas.

15. SUBJECT TERMS

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3. Extended MICOM modeling studies were performed for the Red Sea and Gulf of Aden region which successfully reproduced the magnitude and seasonal cycle of the exchange at the Bab el Mandeb strait and provided insight into the important dynamics governing the regional circulation. The sensitivity of the model results to uncertainties in forcing fields, horizontal grid resolution, and far-field domain size have been thoroughly investigated.

RESULTS

The results from the Strait of Hormuz experiment have been used to estimate the annual mean deep outflow of water from the Arabian Gulf and the heat and freshwater budgets of the Gulf. From our measurements we have determined the annual mean deep outflow from the Gulf to be 0.20 Sv with associated heat and freshwater losses over the Gulf of 20 W/m^2 and 1.9 m/yr, respectively. . We have compared these flux estimates with independent estimates derived from available surface flux climatologies (COADS, SOC, NCEP; Figure 1). These comparisons have shown that there are large and systematic errors in most of the surface flux data sets over the Gulf, which are related mainly to errors in the shortwave/longwave radiation and latent heat fluxes (Smeed et al., 2000). Similar results and flux biases were found for the Red Sea from flux constraints provided by the earlier Bab el Mandeb measurement program (Sofianos et al., 2002). Work with Simon Josey and colleagues at SOC has helped to develop corrections for the radiative fluxes that are applicable to these marginal seas areas, including account of aerosol loading and improvement of the longwave parameterization. We have also compared our results with initial surface flux estimates from mesoscale atmospheric model runs for the region by Dr. S. Chen of RSMAS (Figure 1), which suggest that the mesoscale model fluxes do not suffer from these same large biases.
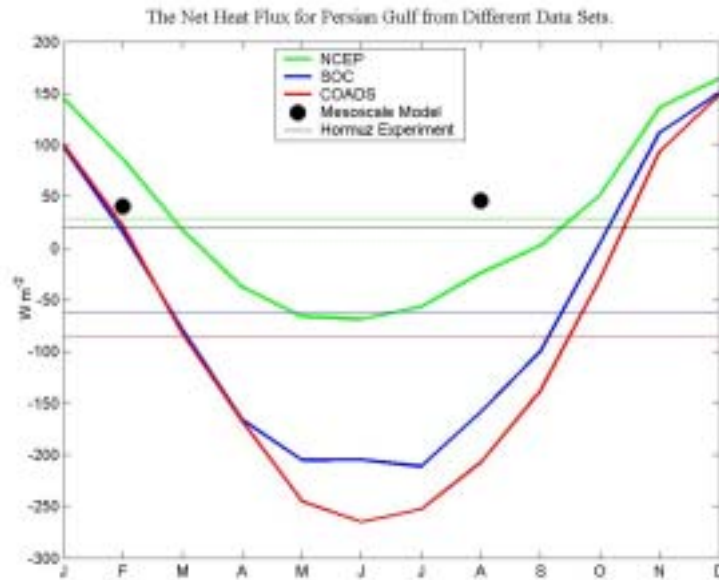

Figure 1. Annual cycle of surface heat loss over the Persian Gulf from available surface flux climatologies (COADS, SOC, and NCEP). The annual mean values of the heat loss for each climatology are indicated by the thin horizontal lines of the same color. The annual mean value derived from the Hormuz Experiment is shown as a thin black line. Also shown are the heat loss values over the Persian Gulf from trial MM5 simulations for the AMSG region in February and August 2001 (courtesy of S. Chen, RSMAS).

Our modeling studies of the Red Sea using a limited-domain version of the Miami Isopycnal Coordinate Model (MICOM) have helped to clarify the relative importance of seasonal wind and buoyancy forcing in driving the Red Sea circulation, and have brought forth a number of new ideas on the circulation dynamics and water mass formation processes in the Red Sea (Sofianos and Johns, 2002a,b). To establish the sensitivity of the model results to variation of forcing fields, all available air-sea exchange data sets over the Red Sea were investigated (UWM/COADS, SOC, NCEP reanalysis, ERBE (Earth Radiation Budget Experiment), and GPCP (Global Precipitation Climatology Project)). The NCEP climatology is by far the closest to the annual mean surface heat flux estimate derived from the Bab el Mandeb data (Sofianos et al., 2002), presenting a heat loss from the Red Sea of ~4 W/m^2, while the others present a significant heat gain. All climatologies underestimate the freshwater loss by about 0.5 m/year, with the SOC climatology being closer to the value produced by our direct observations. To determine the model sensitivity to forcing, the amplitude of the seasonal cycle of the forcing terms was varied over a range consistent with the possible uncertainties and a series of experiments was executed. The results of these experiments showed that, although the main exchange pattern is a robust result, both the strength of the exchange and the pattern of the seasonal cycle can be substantially affected by changes in the seasonal cycle of the forcing fields.

A high resolution MICOM model (~5 km resolution) was implemented for the same domain as the original MICOM model, to investigate the effect of resolution (more complicated topography, more points inside the strait of Bab el Mandeb) on the model performance. The results are almost identical to the previous experiments as far as the exchange flow is concerned, although some of the circulation features inside the Red Sea (gyres and boundary currents) show a greater complexity. An extended domain MICOM model (~10 km resolution), including the Gulf of Aden, was also implemented to examine the effect of a greater domain outside the Red Sea on the model's exchange flow and investigate the Gulf of Aden's seasonal circulation. The experiment was successful, reproducing again the basic pattern of the exchange flow at Bab el Mandeb, and showing the presence of energetic eddy features in the Gulf of Aden consistent with findings from recent observations (Bower et al., 2002).
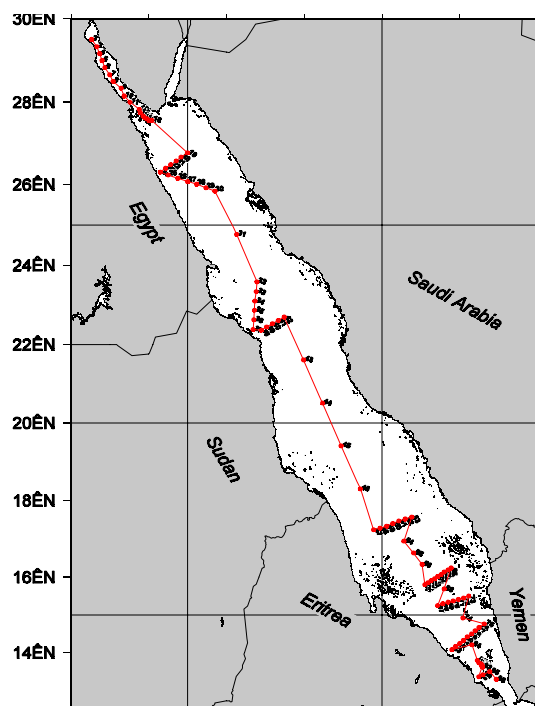

Figure 2. Cruise track and stations for the summer 2001 Red Sea cruise.

To improve the observations available in the region we conducted a 10 day cruise in the Red Sea during August 2001 on the R/V Maurice Ewing while it was underway to the Gulf of Aden as part of an NSF-sponsored study of the Red Sea Outflow plume, in which the P.I. was also involved (Figure 2). More than 90 CTD/LADCP stations were occupied along the axis of the Red Sea and on several cross sections in the northern and southern parts of the basin, including the area of the Hanish Sill in the Bab el Mandeb Strait and in the Gulf of Suez. Extremely high salinities (maximum observed value 42.63 psu) were recorded in the Gulf of Suez (Figure 3a), decreasing from the head to the mouth of the Gulf. The temperature and salinity stratification results in a density pattern that is indicative of dense water formation and outflow from the Gulf. Twenty deep stations were occupied along the main axis of the Red Sea to determine the large-scale meridional stratification in the basin (Fig 3b). As expected, a strong signal was found of the relatively cold and fresh Gulf of Aden Intermediate Water,

3

centered at about 60 m in the southern part of the basin and spreading to the north (undergoing strong mixing into the surface layer at the same time), reaching to a
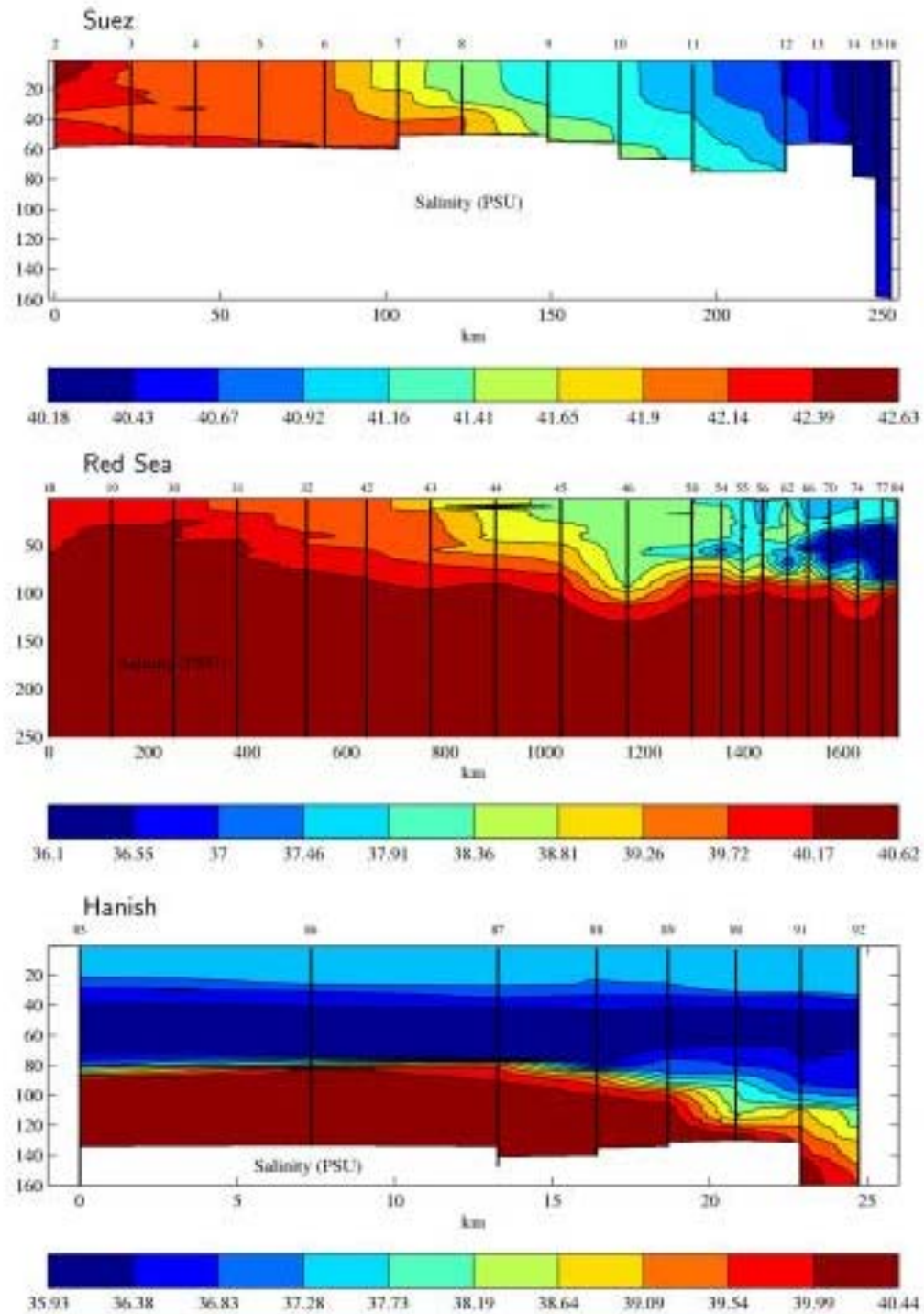

Figure 3. Salinity cross-sections from the August 2001 Red Sea cruise: (a) Gulf of Suez; (b) Red Sea (along central axis); (c) Bab el Mandeb at the Hanish Sill.

latitude of 18°N. The 3-layer exchange was also well established in the strait, including what appeared to be an unusually strong deep RSW outflow for the summer season (Fig 3c). Evidence for relatively strong gyres or eddies in the central part of the basin was indicated by the hydrographic and shipboard ADCP data (not shown), and a tight cyclonic gyre was found in the northern part of the basin in agreement with model predictions.

IMPACT/APPLICATIONS

The observations we have collected in this region have provided the first detailed, long-term time series observations in the Bab el Mandeb and Strait of Hormuz, both strategically important straits, and new data on the summer circulation and hydrography of the Red Sea. These data are providing a new level of understanding of the circulation and exchange processes in these marginal seas and the associated dynamics. Comparative studies with other marginal seas and straits (e.g., Gibraltar) will help to improve and broaden our understanding of the dynamical controls regulating ocean-marginal sea exchange. The heat and freshwater transports determined from these measurements are providing powerful constraints on air-sea fluxes in these regions to help eliminate biases in existing climatologies and operational products.

TRANSITIONS

None

RELATED PROJECTS

Analysis of the Strait of Hormuz and Arabian Gulf data sets is being carried out in collaboration with U.K investigators David Smeed and Simon Josey of the Southampton Oceanography Centre, who performed extensive shipboard surveys in the strait region during the period of the moored deployments and are developing improved surface flux climatologies for the region. We are also working with Dr. Amy Bower of Woods Hole to investigate the hydrography and circulation in the Arabian Gulf in relation to the Strait of Hormuz exchange, and the characteristics of the outflow plume from the Gulf. The recent Red Sea study will share data and results with a related NSF study by the P.I. (in collaboration with H. Peters of RSMAS and A. Bower and D. Fratantoni of WHOI) on the dynamics and spreading of the Red Sea outflow in the Gulf of Aden.

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PATENTS

None.